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How Does Public Information on Central Bank Intervention Strategies Affect Exchange Rate Volatility?

The Case of Peru

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Abstract

Intervention operations in the foreign exchange market are used by the Banco Central de Reserva del Peru to manage both the level and volatility of their exchange rates. The Banco Central de Reserva del Peru provides information to the market about the specific hours of the day interventions would take place and the total amount of intervention. It consistently buys and sells on the foreign exchange market to avoid large appreciations and depreciations of the Peruvian nuevo sol against the U.S. dollar (Sol/USD), respectively. The estimates in this paper indicate that past information on interventions has moved the sol in the intended direction but only during the time the Banco Central de Reserva del Peru has announced it would be active in the foreign exchange market. The authors also find that the expectation of future interventions by the Banco Central de Reserva del Peru decreases the volatility of the sol when it intervenes to avoid an appreciation of the sol; however, the opposite occurs when the intervention takes place to defend the sol from depreciation. Indeed, the sol has been less volatile during periods when the Banco Central de Reserva del Peru has intervened than otherwise.

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How does public information on central bank intervention strategies affect exchange rate volatility? The case of Peru

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Introduction

Some central banks in emerging economies target the exchange rate level while others have other aims: to slow the rate of change of the exchange rate; to dampen exchange rate volatility (in some cases to satisfy an inflation target); to supply liquidity to the forex market; or to influence the level of foreign reserves. Some other central banks have a mixture of objectives. See BIS (2005).

The Banco Central de Reserva del Peru (BCRP) has had an inflation targeting framework for monetary policy since 2002. However, Peru is a dual-currency economy with predominant dollarization, and the BCRP, being aware of such conditions, cannot completely neglect how the exchange rate develops when designing and implementing monetary policy in Peru. The BRCP cannot increase further the inherent risks of the domestic currency, and instead promote the role of the currency as store of value and avoid excessive volatility to avoid harmful consequences. High volatility of the sol/USD could have effects on first, inflation given the degree of openness of Peru; second, international trade because the market for derivatives is not yet well developed in Peru (see Mundaca (2010)); and third, the balance sheets of the Peruvian private sector given the relatively highly dollarized of the economy. Therefore, the BCRP has as mandate to smooth out the path of the exchange rate and avoid high exchange rate volatility by intervening in the foreign exchange market.

The BCRP is also taking measures to promote de-dollarization in its inflation targeting regime, and it is now evident that financial dollarization has steadily decreased over recent years. For example, in 2004, 70% of credit to the private sector was denominated in foreign currency; by the end of 2009, this figure decreased to around 55% (deposits are more or less 50%). The measures that have been taken are using the interest rate (i.e., overnight

interest rates) as an operational target to stabilize and make predictable the relevant short-term interest rates in the domestic currency. This practice should naturally contribute to the development of the yield curve of interest rates for different maturities for public debt in domestic currency. This will in turn foster incentives for issuing long-term instruments by the private sector that can be used to hedge against exchange rate risk and foreign exchange liquidity risks. In addition, the BCRP also requires that commercial banks have large reserves on their foreign currency liabilities. The implementation of these policies to de-dollarize the economy, together with stronger economic fundamentals, should eventually decrease the need to both intervene in the foreign exchange market over time, and accumulate international reserves to carry out such interventions. Furthermore, there are risks involved in making the exchange rate into a nominal anchor for monetary policy and overriding the already institutionalized inflation targeting. The latter may cause shifts in expectations as the market becomes uncertain as to what the BCRP's objectives really are.

The goals of this paper are threefold: i) to briefly present a stochastic optimal control model for central bank interventions in the foreign exchange market similar to that presented in Mundaca and Oksendal (1998); (ii) to empirically test the predictions of our theoretical optimal control model by estimating the Central Bank of Peru's (Banco Central de Reserva del Peru (BCRP)) reaction function for intervening in the foreign exchange market; and (iii) to test the predictions of our model by empirically analyzing the effect of the BCRP's intervention policy on the exchange rate of the Peruvian currency, the sol, against the US dollar and its volatility.

This paper's empirical analysis uses intra-daily exchange rate data from 2004 to 2009. Because the BCRP's interventions are always made public at the end of its official participation in the foreign exchange market, we are able to differentiate between the effect of past information of interventions and expectations of future interventions on the exchange rate. This distinction is important because the whole purpose of making the information on intervention activities public is to reduce uncertainty and to establish that the BCRP is committed to achieving certain goals. Moreover, we use the intervention decisions that are observed by the market to test the significance of the signaling channel (Mussa (1981)) of the intended monetary policies. Expected future and unannounced central bank participation in the foreign exchange market involves a good deal of asymmetric information; as a consequence, uncertainty may or may not dissipate completely. We will study the significance of this uncertainty.

The studies outlined in the relevant literature that examine the effect of central bank interventions on the volatility of the exchange rate have obtained mixed results. However, these differences are mainly attributable to the varying quality of the data used in the empirical exercises, as well as the monetary policy regimes, data frequencies, and the econometric methods used to measure the effects of interventions on the exchange rate.

We use the methodology of Mundaca and Oksendal (1998) to model an optimal intervention policy for central banks to stabilize the exchange rate. Two types of controls are considered: discrete interventions, which cause a jump in the exchange, and continuous small interventions, with the purpose of smoothing variation in the exchange rate. The first control represents the infrequent but large interventions to prevent large variability due to random

events (i.e., political events), and the continuous control takes place to smooth out changes in the sol that inevitably result from adverse changes in economic fundamentals. As in Mundaca and Oksendal (1998), the range of variation of the exchange rate is determined endogenously from the optimal stochastic intervention control problem.

We test our model of stochastic control empirically using intra-daily data. Even when the period within which the BCRP would intervene has been made public (between 11:00 and 13:30 everyday), forward-looking market participants still remain uncertain as to if or when interventions will take place. This uncertainty occurs because on a daily basis, the market does not know how much appreciation/depreciation on one side and volatility on the other side the BCRP is ready to tolerate. The market needs to assess the probability of intervention by the BCRP. Therefore, it should be not only interesting but also useful to analyze the effect of such uncertainty regarding the probability of intervening, and to compare it with the effect that past and public information on interventions may have on both the level and the volatility of the exchange rate itself. To carry out these tasks, our empirical model considers the unannounced future interventions as dichotomous, endogenous variables that both depend and affect the exchange rate. Modeling future interventions as endogenous is realistic because market participants make decisions on the exchange rate, taking into account their beliefs about possible central bank interventions in the foreign exchange markets. Finally, this study shows that the disturbances of the exchange rate mean equation are characterized not only by an autoregressive conditional heteroscedastic (ARCH) process but also by another source of heteroscedasticity, namely their correlation with the intervention variables. Accordingly, we allow expectations of central bank's interventions enter as explanatory variables in the conditional mean and variance of the exchange rate.

The paper is organized as follows. Section 2 presents the theoretical model of the optimal control of the exchange rate. Section 3 includes a quick glance at the key aspects of foreign exchange intervention policies in Peru and a summary of the statistics of the main variables used in the empirical analysis. Section 4 contains the empirical model that is used to test the theoretical model. We present our estimation results of the central bank's intervention and the conditional mean and variance of the exchange rate in Section 5. Section 6 concludes.

1. A theoretical model for the optimal control of the exchange rate

Using the theory of combined stochastic control, we model the monetary authorities as minimizing the total costs of large exchange rate deviation from certain means and of intervening in the foreign exchange market with the purpose of stabilizing the exchange rate. Y_t denotes the level of the exchange rate: sol/USD. The central bank aims to keep Y_t stable and at least close to some average $\overline{Y}$. To achieve its objective, it implements two types of control:

i) The central bank can intervene frequently with small amounts of foreign exchange to smooth the exchange rate's movements. This type of control, m= $(m_t)_{t \in \mathbf{R}}$, is called *continuous control.* The set of all continuous control is denoted by U.

ii) The central bank may intervene in the foreign exchange market forcefully selling or buying a large selected amount of foreign exchange, ξ_j, at discrete

and selected (stochastic) times, θ_j, to avoid drastic changes in the exchange rate. This type of intervention is represented by the double sequence:

$$\upsilon = (\theta_1, \theta_2, ..., \theta_N; \xi_1, \xi_2, ..., \xi_N) . \tag{1}$$

(1) is the *impulse control* in which $N \leq \infty$, $\theta_k \leq \theta_{k+1}$ and $\theta_k \rightarrow \infty$ as $k \rightarrow N$ (so that if N is finite, then $\theta_N = \infty$). The set of all impulse controls is denoted by V.

The pair $w = (m,\upsilon) \in U \times V$ is called a *combined stochastic control*. Large deviations of the exchange rate from its mean on a daily basis, are costly for the economy, but the central bank can apply the controls $w = (m,\upsilon)$ to stabilize the exchange rate and thus reduce these costs. Note, however, that it is also costly for the central bank to implement such controls. Mohanty and Turner (2005) have documented the consequences of too frequent interventions. Consequently, the central bank in this paper will then implement such controls in an optimal manner.

Thus, if the pair $w = (m,\upsilon)$ is implemented, the exchange rate will follow the following stochastic process:

$$Y_t = y_0 + \int_{s=0}^{t} b(m_s)ds + \sigma B_t(\omega) + \sum_{j:\theta_j \leq t} \gamma(\xi_j) \text{; or} \tag{2.1}$$

$$Y_t - y_0 = \int_{s=0}^{t} b(m_s)ds + \sigma B_t(\omega) + \sum_{j:\theta_j \leq t} \gamma(\xi_j) \quad . \tag{2.2}$$

y_0 is the initial value of sol/USD, Y_t; $\sigma > 0$ is a constant; $b(m_s)$ measures the effect of continuous interventions by the central bank, selling ($m < 0$) and buying ($m > 0$) foreign

currency, on the exchange rate; while $\gamma(\xi)$ denotes the effect on the exchange rate of occasional interventions, buying (if $\xi > 0$) or selling (if $\xi < 0$). $B_t(\omega)$ for $\boldsymbol{\omega} \in \boldsymbol{\Omega}$ denotes Brownian motion.

Assume that the discount rate is $\rho > 0$ and that the cost of large deviations of the exchange rate from its mean is $K(Y_t - \bar{Y})$ for $K(x) \geq 0$ for all x. Let R(m) be the cost of applying the continuous control (i.e., not enough economies of scale), and the costs of discrete interventions are denoted by $L(\xi_j) > 0$ (i.e., large sterilizations create conflicts with monetary policy).

Taking into consideration the above, the total and discounted expected cost of applying the *combined intervention control w* is as follows:

$$J^{w}(s,y) = E^{s,y}\left[\int_{s}^{T} e^{-\rho t}(K(Y_t - \bar{Y}) + R(m))dt + \sum_{j:\theta_j \leq T} L(\xi_j)e^{-\rho\theta_j}\right]. \qquad (3)$$

$T \leq \infty$ is a given (fixed) future time and $E^{s,y}$ denotes expectations with respect to the probability law of Y_t with initial value y and mean value $\bar{Y}$. We also assume that the costs of selling foreign currency are not necessarily the same as those of buying foreign currency.

The optimization of equation (3) determines the characteristics of the stochastic process of the sol/USD and the variables governing such a process.[1]

[1] Further details can be found in Mundaca and Oksendal (1998).

2. Key aspects of the foreign exchange intervention policies in Peru and statistical summary

3.1 The Banco Central de Reserva del Peru (BCRP) and its intervention policies

Peru attempts to follow a flexible exchange rate while adopting inflation targeting. The BCRP determines, on a *daily basis*, the implicit band within which the sol is allowed to move against the US dollar. This implicit band is not publicly known, but the BCRP has made it clear that it aims to minimize excessive volatility of the sol. According to Humala and Rodriguez (2009), the BCRP intervenes to reduce excess volatility in the exchange market, but in recent years, interventions also have concentrated on US dollar purchases. Such interventions might indicate that Peru may sometimes prefer a depreciated sol against the US dollar, at least when depreciation is not substantiated by economic fundamentals. As an institutional issue, note that the BCRP has also made known that if it finds it necessary to intervene in the foreign exchange market on any day t, it will do so only between 11.00 am and 1:00 pm on that day. It is also known that decisions to intervene on day t are principally based on observing the sol at 11.00 am and how it has developed with respect to previous days. The public are informed about the total amount of intervention by the BCRP at 1:00 pm. (Armas (2005)).

3.2 Some general stylized facts and a summary of statistics

This paper's data have been obtained from the officials at the BCRP. General statistics of the relevant variables, including those used for the empirical work, are shown in Table 1.

The last three rows in Table 1 show that the exchange rate is on average the least variable between 11.00 am and 1:00 pm on any particular day (represented by $\Delta X_t^{13\text{-}11}$); it is

more variable during the other periods. Recall that the BCRP only intervenes between 11.00 am and 1:00 pm and that this is known by the market.

Table 1. Summary of statistics of variables used in the empirical analysis

Series	*Obs*	*Mean*	*Std. Deviation*	*Minimum*	*Maximum*
Net Interventions	1483	14.5945	60.2236	-443.8000	478.7000
Accumulated Interventions in the last 4 days: $\bar{X}_t^{4days}$	1484	58.5201	194.8345	-1277.0000	1626.4000
Bid price at 1100	1483	3.1726	0.1912	2.4950	3.5055
Ask price at 1100	1483	3.1745	0.1902	2.6920	3.5075
(bid+ask)/2 at 1100:Y_t^{11}	1483	3.1735	0.1906	2.6915	3.5065
Bid price at 1330	1483	3.1721	0.1913	2.4950	3.5035
Ask price at 1330	1483	3.1748	0.1897	2.6940	3.5075
(bid+ask)/2 at 1330:Y_t^{13}	1483	3.1735	0.1904	2.6935	3.5055
SPREAD	1483	0.0774	0.0974	-0.3176	1.5554
$log(Y_t^{11}/ Y_{t-1}^{13})*100:\Delta X_t^{11-13}$	1483	-0.0110	0.4026	-7.6205	8.1808
$log(Y_t^{13}/Y_t^{11})*100:\Delta X_t^{13-11}$	1483	-0.0011	0.2184	-3.5380	2.7790
$log(Y_t^{13}/Y_{t-1}^{13})*100:\Delta X_t^{13-13}$	1483	-0.0122	0.4489	-7.6205	8.1977

Such statistics indicate that the Peruvian sol seems to be less volatile during periods when the BCRP can officially participate in the foreign exchange market. The BCRP has informed the public that regardless of how the exchange rate moves, it does not participate at other times of the day, i.e. between day t at 11.00 am and day t-1 at 1:00 pm (represented by ΔX_t^{11-13}). However, the time interval in which the central bank can be both present and absent is between 1:00 pm at day t and 1:00 pm at day t-1 (represented by ΔX_t^{13-13}).

The following figures show the average between the *bid and ask prices* for the sol/USD observed at 11.00 am (Figure 1) and the percentage change in the exchange rate at different times of the day represented by the difference in the logs of the exchange rate (Figures 2 and 3). Figure 2 shows the differences between the logs of the average bid and ask prices observed at *11.00 am at day t* and the logs of the average bid and ask prices observed at *1:00 pm at day t-1*. $\Delta X_t^{11\text{-}13}$ is the only period in which it is known that the BCRP can be active in the forex. Figure 3, however, shows the difference between the logs of the average bid and ask prices observed at *1:00 pm on day t* and the logs of the average bid and ask prices observed at *11.00 pm on day t*, $\Delta X_t^{13\text{-}11}$, the period in which the central bank is absent in the forex. The development of the (100 times) log difference of the bid and ask at 11.00 am is displayed in Figure 4. Each of the figures also includes the patterns of the net interventions by the BCRP in millions of USD. Net positive interventions indicate net buying of foreign reserves by the BCRP, and negative interventions indicate net selling of foreign reserves.

Figure 1. Sol/USD observed at 11.00 am and Net Interventions by BCRP

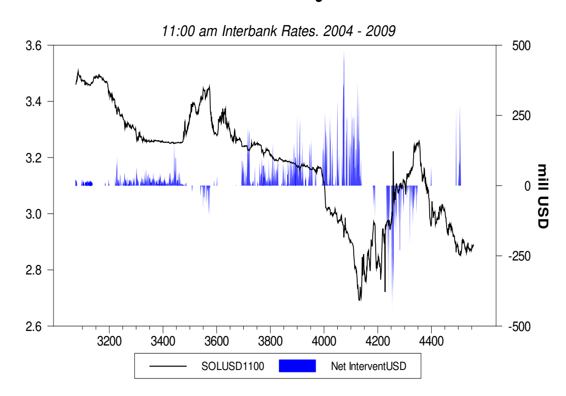


Figure 2. Changes in logs of Sol/USD and Net Interventions by BCRP: $\Delta X_t^{11\text{-}13}$

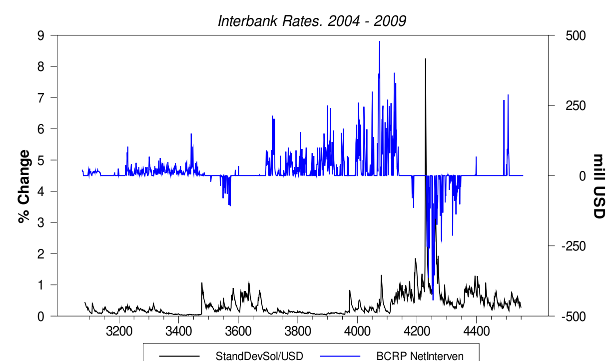


Figure 3. Changes in logs of Sol/USD and Net Interventions by BCRP: $\Delta X_t^{13\text{-}11}$

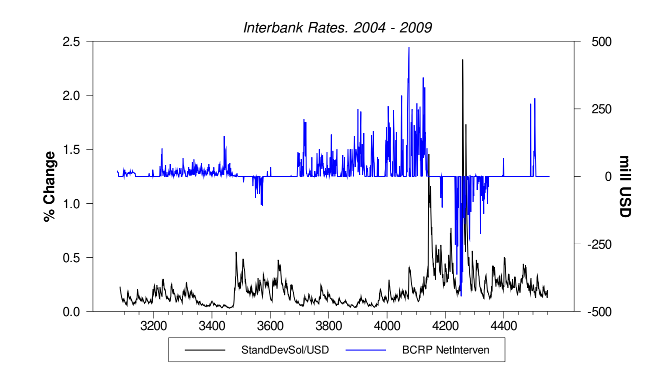
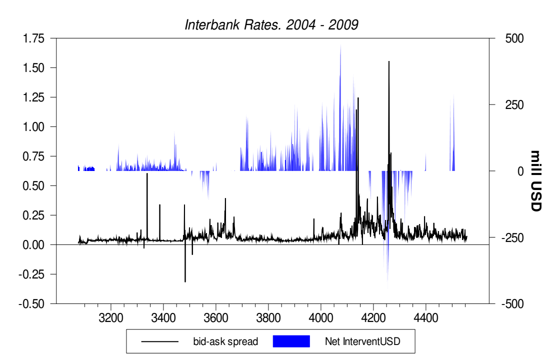


Figure 4. Bid-Ask Spread in the Interbank Rate and Net Interventions by BCRP



Figures 1, 2, and 3 suggest that the BCRP decisions to intervene target both the levels and the changes in the sol/USD. Regarding spreads, it is not clear from Figure 4 whether the BCRP responds to large spreads and makes any attempt to avoid them, but we test for that possibility.

Notice that Figures 2 and 3 confirm the results of the sample statistics on the percentage changes in the exchange rate measured during times when the BCRP has announced that it can intervene and times when the BCRP has indicated it will not intervene in the forex. Notice that during the period between August 2008 (observation 4200) and December 2008 (observation 4300), the sol experienced a rapid depreciation and the highest volatility within the period of study. Nevertheless, the volatility was always smaller between 11.00 am and 1:00 pm on any specific day. We next need to determine whether such distinction is due to the BCRP's intervention policy. How is the behavior of the participants in the exchange rate market affected by BCRP announcing that it will participate and by how much (at the end of its intervention activities)? How do market expectations regarding future

intervention affect the exchange rate level and its volatility? We attempt to answer these questions in the following sections.

3. An empirical model for the sol/USD rate

We test our theoretical model *first* estimating the central bank's reaction function for intervening; and *second,* by estimating the conditional mean and variance of the sol/USD rate. The variance is assumed to follow the Exponential GARCH (1,1) process identified by Nelson (1991) (EGARCH(1,1)). Expected central bank intervention decisions entering in both the conditional mean and variance, are assumed to be endogenously determined. Past information on intervention is also analyzed. The empirical analysis here is an extension of Mundaca's (2001) econometric methodology.

4.1 Reaction functions of the Banco Central de Reserva del Peru (BCRP) for intervening

This section presents an empirical adaptation of the *combined stochastic control,* the pair *w = (m,v)* presented in Section 2, which embodies the central bank's optimal decisions to intervene to smooth the movements of the exchange rate: large and infrequent interventions and continuous interventions in the foreign exchange market. Such optimal decisions should minimize the central bank's costs.

Consider M^B and M^S the variables representing the central bank participation buying and selling foreign exchange, respectively. These decisions to intervene are defined as follows:

$$M_t^B = \delta_{11} apprec_{t-1} + \delta_{12}(X_t^{11} - \bar{X}_{t-1}^{4days}) + \delta_{13} Spread_{t-1} - \mu_t^B . \tag{4.1}$$

$$M_t^S = \delta_{21} deprec_{t-1} + \delta_{22}(X_t^{11} - \bar{X}_{t-1}^{4days}) + \delta_{23} Spread_{t-1} - \mu_t^S \ . \qquad (4.2)$$

The exchange rate used here is the (log) of the average between the *bid and ask prices* observed at 11.00 am, X_t^{11}. Recall that it is public information that the central bank makes decisions after analyzing how the exchange rate has developed until 11.00 am on the day it is evaluating whether to intervene or not. The variables *apprec* and *deprec* represent *only* appreciation and depreciation of the sol with respect to the US dollar between today at 11:00 am and the day before at 1:00 pm (the last time that the central bank could have intervened). Thus, the parameters δ_{11} and δ_{21} will indicate whether the central bank only buys foreign exchange when the sol appreciates, or sells only if the sol depreciates. $\bar{X}_{t-1}^{4days}$ is the log of the average change in the sol/USD over the last 4 days observed at 11:00 am. The spread is (100 times) the difference in logs of the bid and ask prices observed at t-1. We consider the possibility that the central bank may be interested in correcting sufficiently large spreads by intervening to alleviate lack of liquidity.

The market (and the econometrician) does not know the precise timing for *future* central bank interventions, and they consequently needs to form expectations about the central bank participation in the forex market. In view of this, we model intervention decisions, M^B and M^S, as qualitative variables. M^B and M^S are greater than zero if the central bank intervenes and zero otherwise. We define the dummy variables I^B and I^S, which are going to be related to M^B and M^S in the following manner:

$$I_t^B = 1 \text{ iff } M_t^B = Z_t^B\delta^B - \mu_t^B > 0$$

$$I_t^B = 0 \text{ iff } M_t^B = Z_t^B\delta^B - \mu_t^B = 0 \quad (5)$$

$$I_t^S = 1 \text{ iff } M_t^S = Z_t^S\delta^S - \mu_t^S > 0$$

$$I_t^S = 0 \text{ iff } M_t^S = Z_t^S\delta^S - \mu_t^S = 0.$$

Also, $\delta^B = (\delta_{11}, \delta_{12}, \delta_{13})$; $\delta^S = (\delta_{21}, \delta_{22}, \delta_{23})$; and Z_t^B and Z_t^S are matrices of explanatory variables accompanying the δ's of the decisions to intervene as defined in equations (4.1) and (4.2).

We use the probit ML to estimate the parameters in (4.1) and (4.2), taking into account (5) and using intra-daily data for the sol/USD between 2004 and 2009. Now, μ_t^B and μ_t^S are random disturbances with the following distributions:

$$\mu_t^B \sim N(0,1);\ \mu_t^S \sim N(0,1); \text{ and } cov(\mu_t^B\mu_t^S) = 0.$$

4.2 Empirical specification of the model for the exchange rate

Estimation of the model containing equations (2) and (3) requires identification and estimation of their parameters. Note that the central bank is assumed to minimize the cost of intervening, which implies minimization of $K(Y_t - \bar{Y})$, $R(m)$, and $L(\xi_j) > 0$. Once this minimization is achieved, the exchange rate is expected to evolve as described in (2). We need to determine an econometric specification to estimated parameters of equation (2). Let us consider a possible econometric specification for the conditional mean of sol/USD:

$$E_t[\Delta X_t] = W_t\beta + \varepsilon_t. \quad (6)$$

$E_{t+1}[\Delta X_t]$ is the expected change in the exchange rate. W_t includes lags of ΔX_t and central bank interventions in the foreign exchange market, both *past* and *expected future interventions*.

As mentioned above, the BCRP does not intervene on any day earlier than 11.00 am or later than 1:00 pm. This is common knowledge to the market, and the BCRP announces the total amount of its intervention **each day** after finishing its participation in the foreign exchange market at 1:00 pm. Nevertheless, on any particular day, participants in the market (and the econometrician) are unable to know the exact timing of past and future possible interventions. Note that receipt of a signal is not the same as a materialized intervention. The actual time and amount of intervention occurring during the day are never made public.

Our specified equation (6) emphasizes the simultaneous determination of the *expected exchange rate* and these *expected future interventions*. We designed our empirical model to capture this simultaneity as accurately as possible. In this regard, we consider that the BCRP makes decisions about whether to intervene or not every day at around 11.00 am. We also consider that at the same time, market participants form expectations about both possible central bank interventions and the future exchange rate at different time periods in a specific day. With regard to the expectations of the market participants, the following strategies are adopted:

- ***Strategy 1:*** We consider how the market forms expectations about a possible exchange rate change between 1:00 pm the previous day (which is the time when the BCRP publishes its intervention activities and the last exchange rate observation the

econometrician has available in any particular day) to 11.00 am today. Keep in mind that during this period, the BCRP has committed to not intervene at all in the foreign exchange market.

- ***Strategy 2:*** We consider how the market forms expectations about a possible exchange rate change between 11.00 am and 13.30 pm on the same day.

Strategy 1 truly and solely represents how potential central bank interventions in the permitted time frame affect the formation of market expectations on the exchange rate. *Strategy 2* allows us to capture partly the effect of signals on actual interventions and partly the effect of expectations that interventions might take place between 11.00 am and 1:00 pm. Note that even though the BCRP does not publicize its intervention activities until 1:00 pm every day, the market might receive some signals as to whether the BCRP is present in the forex between 11.00 am and 1:00 pm and yet an actual intervention might not materialize. Thus, the *two strategies* comprise a period when the BCRP has announced it will intervene and a period when the BCRP has committed to not intervene at all.

Now, following the arguments presented above and bearing in mind that independent of what assumptions we make about the disturbance ε_t, equation (6) alone cannot represent the correct process for the exchange rate because *future expected* central bank interventions are endogenous. Here, we hypothesize that future central bank decisions to intervene affect the exchange rate, and such decisions depend on the exchange rate itself. To obtain consistent estimates, one must therefore consider that the disturbance ε_t is correlated with these future intervention decision variables. More specifically, the error terms of the central bank's reaction functions for intervening, μ_t^B and μ_t^S will be correlated with ε_t. Thus, the estimation

method needs to take into account (4.1), (4.2) and (5) together with (6). Taken together, these equations constitute an endogenous switching regression model for the exchange rate where the switch is defined by the criteria functions (4.1), (4.2) and (5) (see Johnson and Kotz (1972), Olsen (1980) and Mundaca (2001) for further details). That is

$$E_t[\Delta X_t \mid M_t^B > 0; M_t^S > 0; \Omega_{t-1}] = \beta_1 \Delta X_{t-1} + \beta_2 \Delta X_{t-2} + \alpha Interv_{t-1} + E_t[\varepsilon_t \mid M_t^B > 0; M_t^S > 0; \Omega_{t-1}]$$

$$= \beta_1 \Delta X_{t-1} + \beta_2 \Delta X_{t-2} + \alpha Interv_{t-1} - \sigma_{\varepsilon\mu^B} E_t[\mu_t^B \mid \mu_t^B < Z_t^B \delta^B; \Omega_{t-1}] - \sigma_{\varepsilon\mu^S} E_t[\mu_t^S \mid \mu_t^S < Z_t^S \delta^S; \Omega_{t-1}]$$

$$= \beta_1 \Delta X_{t-1} + \beta_2 \Delta X_{t-2} + \alpha Interv_{t-1} + \sigma_{\varepsilon\mu^B} \left(-\frac{\phi(Z_t^B \delta^B)}{\Phi(Z_t^B \delta^B)} \right) + \sigma_{\varepsilon\mu^S} \left(-\frac{\phi(Z_t^S \delta^S)}{\Phi(Z_t^S \delta^S)} \right). \tag{7}$$

In (7), Ω_{t-1} represents all information available up to time t-1. We consider different AR orders for ΔX_t and found that the best representation is AR(2) for ΔX_t. Note that the hazard functions $\phi(Z_t^B\delta^B)/\Phi(Z_t^B\delta^B)$ and $\phi(Z_t^S\delta^S)/\Phi(Z_t^S\delta^S)$ are the truncated means of $E_t[\mu_t^B|\mu_t^B < Z_t^B\delta^B]$ and $E_t[\mu_t^S|\mu_t^S < Z_t^S\delta^S]$, respectively, and they represent the conditional distributions of M_t^B and M_t^S. More intuitively, the hazard functions represent the rates at which the intervention spells are completed in a specific day, given that they took place that day. We include information on interventions, $Interv_{t-1}$, which are common knowledge to the market on the day and time that the BCRP decides whether to intervene or not. The disturbance of the mean equation (7), for example, η_t, is assumed to have zero mean and certain conditional variance. This variance is assumed to follow an Exponential GARCH(1,1) (EGARCH(1,1)) process which was introduced by Nelson (1991), but it also includes the effect of central

banking interventions: both past interventions observed by the market and the squares of the hazard functions. We then redefine Nelson's natural logarithm of the conditional variance as follows:

$$\ln(h_t) = c + a_1 \frac{\eta_{t-1}}{\sqrt{h_{t-1}}} + \kappa \left[\left| \frac{\eta_{t-1}}{\sqrt{h_{t-1}}} \right| - \sqrt{\frac{2}{\pi}} \right] + b_1 \ln(h_{t-1}) - \rho_B \left[\frac{\phi(Z_t^B \delta^B)}{\Phi(Z_t^B \delta^B)} \right]^2 - \rho_S \left[\frac{\phi(Z_t^S \delta^S)}{\Phi(Z_t^S \delta^S)} \right]^2 + \theta Interv_{t-1} \quad . \quad (8)$$

The EGARCH models are motivated by evidence that large negative shocks have a larger effect on volatility than corresponding large positive shocks. Historical volatility measures, including GARCH models, do not capture this asymmetry. Another advantage of the EGARCH model is that there is no need to artificially impose non-negativity constraints on the model parameters. This is made possible because for the conditional variance, one models $\log(\sigma^2)$. Note that we also assume an EGARCH(1,1) process for the exchange rate, assuming t-distribution for the error terms to account for the leptokurtosis of the exchange rate.

The strategy to estimate (4.1), (4.2), (5), (7) and (8) consists of a two-stage method suggested by Heckman (1978) and Lee (1978). In the first step, we estimated (4.1) and (4.2) with observations I^B and I^S as a typical Probit model to obtain the estimates of the δ's and thereafter $\phi(Z_t^B\delta^B)/\Phi(Z_t^B\delta^B)$ and $\phi(Z_t^S\delta^S)/\Phi(Z_t^S\delta^S)$. In the second step, equations (7) and (8) are estimated by numerically maximizing the likelihood function for the EGARCH(1,1) model.

Again, by specifying the logarithm of the variance h_t as a function of η_t, Nelson ensured that the conditional variance stays positive even if some of the coefficients in (8) are negative. Introducing $\left|\sqrt{\eta_{t-1} / h_{t-1}}\right|$ permits us to analyze whether positive or negative values of η_t will increase or decrease the conditional variance.

4. Estimation results

5.1 The intervention equations

We estimate the parameters of the intervention criteria, equations (4.1) and (4.2), with observations I_t^B and I_t^S as a standard probit model. These estimates are presented in Table 2.

Table 2. Probit estimates of the criteria functions for intervening.
(Standard errors are in parentheses.)

Dependent Variable M_t^B		***Dependent Variable M_t^S***	
Coefficients	*Estimates*	*Coefficients*	*Estimates*
δ_{11}	0.3810	δ_{21}	-1.1235
	(0.0633)		(0.0821)
δ_{12}	-0.3855	δ_{22}	1.0463
	(0.0769)		(0.0817)
δ_{13}	-8.0346	δ_{23}	-4.8294
	(0.5882)		(0.3789)
Observations	1469		1469
Log Likelihood	-879.26		-647.79

The results indicate that the central bank seems to be consequent in its intervention decisions. That is, the probability of intervening buying (selling) foreign currency increases when the exchange rate observed at 11.00 am (ask price) at time t appreciates (depreciates)

with respect to its value the day before (at t-1), also observed at 11.00 am.[2] The behavior of the exchange rate during the preceding 4 days is also important to the intervention decisions of the BCRP. For example, if the sol appreciates with respect to the average exchange rate in the preceding 4 days, the probability of intervening by buying foreign currency increases. This probability is reduced, however, if the sol depreciates. Similarly, it is more likely that the BCRP will sell foreign currency if the sol depreciates with respect to the previous 4 last days.

Regarding the spread, we find that a widening of the bid-ask spread reduces both the probabilities of selling and buying foreign currency. As we know, the bid-ask spread is an important part of transactions costs for international trade and investment. A widening of this spread decreases a firm's profit and thus discourages it from engaging in international trade or investment. It is therefore surprising that the BCRP does not seem to be addressing its intervention policy toward reducing the spread.

In conclusion, the BCRP appears to have a consistent intervention policy in the sense that it avoids large variations of the exchange rate while allowing a smoothing of changes in the exchange rate on a daily basis. The BCRP seeks to avoid large and quick appreciations and depreciations of the sol by buying and selling foreign currency, respectively. We have yet to test whether such a well intended intervention policy actually decreases the volatility of the sol against the USD and moves the sol in the desirable direction.

[2] Other times were also considered but never resulted in significant parameters.

5.2 The effect of interventions on the exchange rate

We will now present and explain the estimates of our EGARCH model, in which we make the conditional mean (equation (7)) and the conditional variance (equation (8)) depend on the interventions decisions by the BCRP. The estimates are shown in Table 3, and those in bold are at least significant at the 5% level. Notably, our results do not support the random walk hypothesis because the autoregressive parameters and the expected interventions and/or past information on interventions affect future changes in the conditional mean of the exchange rate. The empirical results can be summarized as follows:

(a) *Common knowledge past interventions* (previous day) seem to have a desirable effect on the expected change in the exchange rate, but only between 11.00 am and 1:00 pm on the same day ($\Delta X_t^{13\text{-}11}$), the period when the BCRP has committed to intervene if necessary and optimal. However, during the time interval when the BCRP is totally absent in the forex market, there are undesirable effects on the expected exchange rate changes between 11.00 am today and 1:00 pm the day before ($\Delta X_t^{11\text{-}13}$). For example, the previous day's interventions of selling (buying) foreign currency seem to have further depreciated (appreciated) the sol during those times. This result could mean that information regarding past interventions can only successfully affect market expectations in the right direction and remind market participants that the central bank is committed to avoid large variations of the sol between 11.00 am and 1:00 pm.[3]

[3] We also considered accumulated intervention over 5 and 6 days; the results remained qualitative unchanged.

Table 3. Estimated parameters of the conditional mean and variance for the sol/USD. (Standard errors are in parentheses)

Explanatory Variables	Effect on $\Delta X_t^{11\text{-}13}$	Effect on $\Delta X_t^{13\text{-}11}$
MEAN EQUATION		
β_1	**0.0986**	-0.0184
	(0.0245)	(0.0141)
β_2	0.1246	**0.0414**
	(0.0225)	**(0.0172)**
α	**-0.158×10^{-3}**	**0.168×10^{-3}**
	(0.349×10^{-4}	**(0.472×10^{-4})**
$\sigma_{\varepsilon\mu^B}$	**0.0332**	0.0030
	(0.0038)	(0.0058)
$\sigma_{\varepsilon\mu^S}$	**-0.0330**	0.0023
	(0.0029)	(0.0040)
VARIANCE EQUATION		
c	**-0.4390**	**-0.4055**
	(0.0495)	**(0.0661)**
a_1	**0.7391**	**0.5152**
	(0.1801)	**(0.0775)**
κ	**0.1080**	0.0043
	(0.0431)	(0.0356)
b_1	**0.9675**	**0.9686**
	(0.0077)	**(0.0100)**
ρ_B	**-0.0103**	0.0023
	(0.0045)	(0.0056)
ρ_S	**0.0193**	-0.0036
	(0.0072)	(0.0091)
θ	0.482×10^{-3}	0.204×10^{-3}
	(0.352×10^{-3})	(0.327×10^{-3})

(b) *Expectations about future central bank interventions in spite of public information regarding previous interventions* do not have desirable effects or have no effect at all on expected future exchange rates. On one hand, we find that market expectations about future central bank participation by selling (buying) foreign currency causes additional depreciation (appreciation) of the sol during the time period when the BCRP does not participate in the forex. Here, we refer to the effect on $\Delta X_t^{11\text{-}13}$. On the other hand, expected changes in the exchange rate between 11.00 am today and 1:00 pm on the same day ($\Delta X_t^{13\text{-}11}$) appear to be independent of probabilities (as represented by the hazard functions) that the BCRP might become active in the forex during that time. As explained above, the market only seems to care what the BCRP has done in the past when it forms expectations on the exchange rate in a particular day only between 11:00 am and 1:00 pm. It is only during such period that there will be desirable effects on the expected exchange rate. During other times of the day, there are other factors more than potential future expectations that drive market expectations. The market may not believe in the effectiveness of future interventions, even when there is a high probability that they will take place.

(c) Regarding the effects on the *conditional variance*, we find that *past information on interventions* has no effect on the conditional variance of the expected changes in the exchange rates at the different time intervals, which are on $\Delta X_t^{13\text{-}11}$ *and* $\Delta X_t^{11\text{-}13}$. *Probabilities of future central bank interventions* (as represented by the hazard functions) have *no effect* on variance of the expected changes of the exchange rate *within one day* ($\Delta X_t^{13\text{-}11}$), even when this is the period in which the BCRP can intervene. However, for

exchange rate changes between today and yesterday ($\Delta X_t^{11\text{-}13}$), a higher probability that the BCRP will intervene in the future by buying foreign currency to avoid drastic appreciation of the sol against the USD decreases the volatility of the sol. In contrast, an expectation of higher participation by the central bank to defend the sol against the USD, or strong sol depreciation, causes higher volatility of the expected changes in the exchange rate (again on $\Delta X_t^{11\text{-}13}$). This effect is almost twice as strong as the effect of buying foreign currency to avoid appreciation of the sol. These results might explain why the statistical standard deviation of the expected changes in the exchange rate within one day seem to be smaller than the expected changes in the exchange rate between today and the previous day. The latter period coincides with the periods in which the central bank participation in the forex is not expected.

Figures 5 and 6 show the conditional standard deviation of the change in the log of the Sol/USD, $\Delta X_t^{11\text{-}13}$ *and* $\Delta X_t^{13\text{-}11}$, respectively, together with the net interventions.

Figure 5. EGARCH(1,1) Conditional Standard Deviation of $\Delta X_t^{11\text{-}13}$ and net BCRP interventions

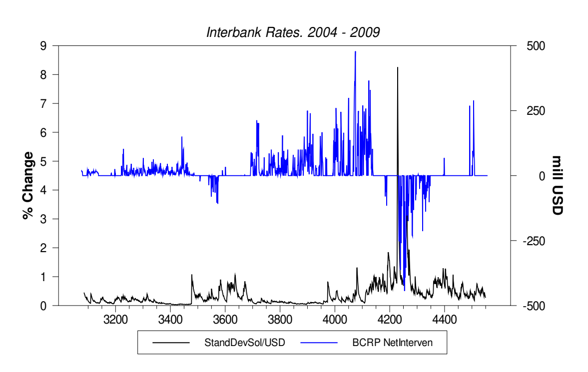
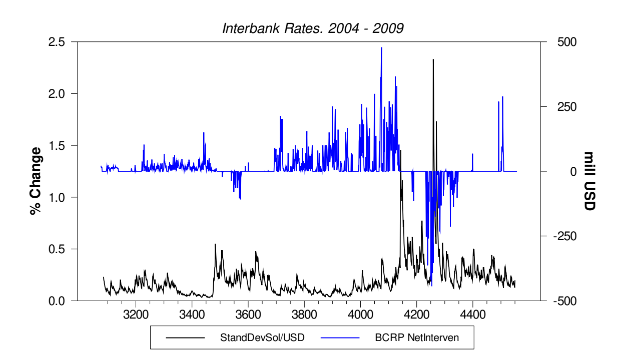


Figure 6. EGARCH(1,1) Conditional Standard Deviation of $\Delta X_t^{13\text{-}11}$ and net BCRP interventions



Note that between August 2008 and December 2008 (between the 4200 observation and the 4300 observation), at the worst period of the recent financial crisis, the sol depreciated a great deal and there were large numbers of interventions by selling USD, as illustrated in Figure 1. During the same period, the changes in the sol/USD (Figure 2) and its conditional standard deviation (Figure 5) were very large, especially during the time the BCRP did not intervene at all: between 11.00 am today and 1:00 pm the day before. This result is in contrast to the amount of volatility during the time the BCRP can intervene, between 11.00 am and 1:00 pm on any given day (see Figure 3 and Figure 6). We can then conclude that larger variations of the sol will most likely occur during those times when the sol depreciates and the BCRP does not intervene.

(d) We also found evidence of asymmetric effects of the shocks on conditional volatility. For example, if one considers the period during which the BCRP does not intervene, for given h_{t-1}, a shock causing one-unit decline in ε_{t-1} (e.g., an appreciation in the sol) induces a change in the log of conditional variance by – **0.6311** units (= (0.7391)*(-1) + (0.1080)*(|-1|)), which implies a decrease in the conditional variance. Furthermore, for a given h_{t-1}, if a shock gives a rise in ε_{t-1} by one unit (e.g., a 1% depreciation of the sol), there will be an increase in the (log) conditional volatility by **0.8471** units (= (0.7391)*(1) + (0.1080)*(|1|)). However, during the time frame in which the BCRP does intervene, the effects on exogeneous shocks on the variance are smaller than they are during the period the BCRP is not active. That is, for given h_{t-1}, a one-unit decline in ε_{t-1} (e.g. a 1% appreciation of the sol) induces a change in the log of conditional variance by – **0.5109** units (= (0.5152)*(-1) + (0.0043)*(|-1|)), which implies a decrease in the conditional

variance. Furthermore, for given h_{t-1}, if ε_{t-1} rises by one unit (e.g., a 1% depreciation of the sol), it causes an increase in the (log) conditional volatility by **0.5195** units (= (0.5152)*(1) + (0.0043)*(|1|)). Thus, if one considers the crisis of 2008 as a "depreciation" shock to the sol/USD, an increase in ε_{t-1}, because there was a shortage of US dollars worldwide and most currencies in both the developed and developing world depreciated, then one can conclude that any increase in sol volatility must have been due to the effect of such crisis. It must have been difficult for the BCRP to decrease the sol volatility caused by the worldwide effect of the 2008 crisis, as our results indicate. Not even past information on central bank interventions that became common knowledge to the public dissipated the uncertainty in the market.

In sum, we have shown that the BCRP's intervention policy is consistent in buying USD when the sol appreciates and selling USD when the sol depreciates. We also find that public information about past interventions has been effective in moving the sol in the intended direction. However, this information seems to have had these effects only during times when the BCRP has informed the market that it will intervene and when interventions were considered necessary and optimal. Thus, both public information about interventions and the BCRP's determination to intervene in an optimal manner have been useful in moving the sol in the desired direction during times of BCRP forex interventions. However, the market does not seem to be affected by past BCRP intervention policy when forming expectations about the exchange rate during times when the BCRP is absent from the forex. Overall, the BCRP does not yet seem to have established a sufficiently strong reputation such that market participants can predict the BCRP's future participation in the forex. Moreover, expectations

formed during times when the BCRP is absent from the forex appear to increase the volatility of the sol when this currency is on a depreciating trend.

It is quite possible that the BCRP may need additional time, relative to the time period covered by the data available here, to establish the desired reputation. A crucial question remains as to whether there is any gain for the BCRP in maintaining a "low volatility" sol only during a certain (relatively short) period each day. Note that we are not suggesting that the BCRP should necessarily intervene much more extensively and frequently; this type of action can be very costly in terms of foreign exchange reserves, which can be used optimally for other purposes. The Peruvian monetary authorities should carefully evaluate the costs and benefits of intervening in the forex given their success in maintaining inflation targeting and a relatively open capital market. In the meantime, it would be advisable for Peruvian policymakers to concentrate on reforming their financial markets and developing financial instruments that will permit hedging against exchange rate risks and reduce the degree of dollarization of the Peruvian economy. As long as the degree of dollarization remains high, policymakers will argue that it is important for them to intervene in order to reduce the volatility of the sol relative to the dollar, especially to avoid a significant appreciation of the sol (because this tends to erode the value of the country's dollar asset holdings). It will be important to free the Peruvian economy from this straitjacket.

Our results present some support for the "signaling channel" effect of interventions (Mussa (1981)), which means that by making past intervention activities public, the BCRP transmits information about its exchange rate objectives. This policy appears to be able to move the sol in the desired direction, but it can do so only during times when the BCRP participates in the forex. Such information gives the BCRP some assurance that its intentions

are being fulfilled: that it will participate in the forex during the hours it has committed to do so. However, past information apparently has created some uncertainty about future movements of the sol, and this has not been helpful for the BCRP in its attempts to establish policy credibility.

Finally, and importantly, it is also possible that interventions magnify rather than dampen the effects of shocks to the sol/USD exchange rate, especially for shocks that cause a depreciation of the sol against the USD. A final recommendation from the above results is that the BCRP should also address the problem of large bid-ask spreads. Further research should investigate whether interventions affect the bid-ask spread and whether the volatility of the exchange rate affects this spread. Naranjo and Nimalendran (2000) hypothesize that interventions create significant adverse selection problems for dealers. They find that dealers increase exchange rate spreads around the time of interventions and suggest that in doing so, dealers protect themselves against the greater information asymmetry of such circumstances.

5. Conclusions

We have considered how interventions affect the process for the exchange rate of sol/USD, both its conditional mean and variance. Expected future participation of the BCRP in the foreign exchange market has been modeled as endogenous, a subject that is rarely taken into account in the relevant literature. We think that our methodology is useful when modeling central bank interventions in the forex.

Regarding the reaction function for intervening, we found that the BCRP consistently attempts to move market expectations in the correct direction by buying and selling foreign exchange currency to prevent drastic appreciation or depreciation of the sol against the USD.

We have considered the formation of market expectations about the exchange rate during different times of the day. We specifically considered expectations regarding formation of the exchange rate during the time the BCRP is active in the forex and during the time the BCRP has committed to not participate in the market.

Our empirical analysis indicates that the *BCRP's past information on interventions* has been successful in causing the market to expect the sol to move in the desired direction, but *only* during the time the BCRP is active in the forex. Thus, market expectations about the future exchange rate at other times of the day were not favorable, as the market might have expected that the exchange rate will move in the opposite direction of what the *past* intervention policy intends. But making past BCRP participation in the forex publicly known does not have any effect on the volatility of the sol at any time of the day.

Expectations of future interventions do not move the exchange rate along the intended path, and may even cause some excess volatility of the sol, especially when the sol depreciates against the USD. One could, of course, appeal to the work of Morris and Shin (2006), who demonstrate that even when information (e.g., about past interventions) becomes common knowledge, asymmetric informational problems may result in coordination failures. Thus, public information regarding past interventions can easily be interpreted differently by each market participant and fail to coordinate what public information really means. Such a theory could explain why the future expected BCRP activities are not always successful in decreasing volatility and moving the exchange rate in the right direction.

By modeling the conditional volatility of the sol/USD as an EGARCH (1,1) process, we find evidence that there are asymmetric responses of volatility to positive and negative shocks.

As a final recommendation, the BCRP should try to address the problem of large bid-ask spreads. Further research should investigate whether interventions affect the bid-ask spread, and even whether the volatility of the exchange rate affects such spread. This is very important for participants in foreign trade and investment who are involved in foreign exchange transactions in general.

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